# Energy Research and Development Division FINAL PROJECT REPORT

# RWE SCHOTT SOLAR FREE-STANDING PHOTOVOLTAICS ARRAY MOUNTING SYSTEM

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Prepared by: RWE Schott Solar, Inc

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### **PREFACE**

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# **ABSTRACT**

RWE Schott Solar, Inc., has developed a new photovoltaic array mounting system, designed to simplify and reduce costs for the installation of PV arrays on flat-roof buildings. During this project, specifications for a flat-roof PV system were generated. A new mounting system was designed to meet those specifications. Project personnel conducted extensive testing and performance analyses on the new mounting system. RWE Schott Solar's new free-standing mounting system, termed the FS system, supports PV arrays at a 5- degree tilt angle and requires no roof penetrations. Both large-area modules and mechanical assemblies of smaller PV modules can be used with the new mounting system. Testing was performed in a wind tunnel and computational fluid dynamics analyses were conducted to ensure that the FS system could withstand wind speeds up to 130 mph. During the course of this project, the FS system was certified for compliance with building codes in Seismic Zone 3 and Zone 4, the most severe seismic zones in the United States.

**Keywords**: Solar, photovoltaic, PV array, flat-roof PV system, PV mounting, PV wind analysis, PV seismic design, PV tilt angle, FS System

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### **EXECUTIVE SUMMARY**

#### Introduction

There is a growing market in the United States for photovoltaic (PV) systems that operate along with existing grid electricity supply and that can be safely and simply installed on the rooftops of businesses, factories, schools, hospitals, and other commercial establishments. The free-standing PV system developed by RWE Schott Solar under this PIER contract is a novel design for mounting photovoltaic modules on flat roofs typically found on commercial buildings.

# **Project Objectives**

The objective was for RWE Schott Solar (RSS) to develop a PV mounting system that would allow PV modules to be easily mounted on a flat rooftop. The desired goals of this new PV mounting system were:

- Eliminating the use of additional ballast materials
- Eliminating penetrations of the roof for PV array anchoring
- Lowering the cost
- Making it easy to install
- Providing a modular design (allowing array increments of any size and utilizing different PV modules)

# **Project Outcomes**

This project was instrumental in achieving significant improvements in the design of the FS PV system, including:

- FS System requires no additional ballast and no roof penetrations
- Adaptability to several industry standard PV module sizes, including ASE-300 modules, and assemblies of smaller modules, such as the SAPC-165 and Shell SP-150
- A 5 degree tilt with an open architecture to promote air circulation for PV module cooling and moisture removal from the roof surface
- Weight of the PV array and mounting equipment is at or below 3 pounds per square foot
- Use of durable materials for long life and a lightweight, mechanically linked array structure to ensure reliable, long-term performance
- Dynamic design that allows, under extreme wind conditions, the front mounting bracket to extend itself upward in response to the pressure differential on the PV module, thereby releasing wind pressure and limiting uplift forces
- Certification of the FS system for zones with winds up 130 mph

- Certification for a penetrationless method to meet code requirements for anchoring the PV array to a building roof in any seismic zone in the United States.
- Costs of the mounting hardware reduced to 5 percent of the total installed cost of the system
- identification of a means to achieve further cost reduction of 20 to 35 percent in fabricating the FS hardware through vendor selection and volume purchasing strategies
- Development of an FS PV system installation manual for both the ASE-300 PV modules and the three-module assemblies of SAPC-165 PV modules
- Electronic permit package to support preparation of permit applications

The completed FS PV system comprises distributed mounting stands, each consisting of a base plate, a tall bracket, and a short bracket. The base plates incorporate an adhered cushioning material on the underside to protect the roof surface.

Figure 1: Demonstration FS System on the La-Z-Boy Retail Store in Rancho Cordova, California



Figure 2: FS System Shown With SAPC-165 PV Modules at a Site in California

#### Conclusions

The free-standing PV system developed under this project has become the flagship PV system offered by RWE Schott Solar Inc. Market acceptance of this PV system has been excellent, and the market demand for penetrationless PV array mounting solutions seems to be growing rapidly. Cost remains the dominant driver for increasing the sales of the FS system. At present, the market price for a turnkey FS system is in the range of \$7–\$8/Watts alternating current (Wac). Payback on such a system can be as short as 6–10 years, depending upon the retail electric rates. In the coming years, the company expects to install many megawatts of PV using the FS system.

#### Recommendations

This project has identified several opportunities to advance the design of the new FS mounting system. They are:

1. Higher Tilt Angle Version: The current design supports the PV modules at a 5 degree tilt angle. This allows PV arrays to be packed fairly densely in a given roof space, which is important to many customers in the California market. If a 14 degree tilt angle array could be engineered and could withstand the same wind forces, a PV array could generate 4percent to 6 percent additional annual energy. For a performance- or energy-based contract or state rebate program, this higher tilt design could be very valuable.

- 2. ICC Review and Certification: The International Codes Congress (ICC) is the organization that certifies building inspectors and offers an evaluation service, and they will certify a commercial building product for compliance with the building code. ICC certification would be a significant commercialization step.
- 3. Template: A layout template was built to facilitate placement of the base plates. The authors found that repeated measurement was quicker, but recommend the development of a better template that would be quick and easy to use.
- 4. Baseplate: Finding a lower cost material for the baseplate to replace the stainless steel now being used could reduce the product cost 10 cents to 20 cents per watt.

#### Benefits to California

California has adopted a Renewable Portfolio Standard designed to help achieve a statewide energy-production mix with 20 percent from non-large-hydro renewable energy sources by the year 2017. Rooftop PV systems can make a significant contribution toward this goal.

The benefits to California of widespread deployment and use of PV installations include the obvious intrinsic advantages of photovoltaic energy that derive from less reliance on fossil fuels, and reduction of air emissions from fossil-fuel power plants. Producing energy with photovoltaic systems prevents tons of carbon dioxide, nitrous oxides, sulfur dioxide, and particulates from fouling the air. Those traditional power plant emissions are contributors to both the development of smog and acid rain, and untold deleterious health effects. Greater reliance on our indigenous solar resources also increases California's nation's energy security by diversifying our energy mix and lessening our dependence on fossil fuels.

Since the product's introduction in the summer of 2003, FS systems have been deployed in approximately 100 locations in California, Washington, New Jersey, and Massachusetts, accounting for a total of approximately 6 megawatts (MW) of PV. The FS system is the flagship product of RWE Schott Solar Inc. and it has been warmly received in the marketplace.

Figure 3: Photo Gallery of Example FS Systems Installed in 2003















# **CHAPTER 1:** Introduction

This section of the report provides an overview of RWE Schott Solar and the background of the development of the free standing (FS) mounting system.

# 1.1 Background and Overview

RWE Schott Solar, Inc. was formed in 2002/3, bringing together the system design, engineering, marketing and sales of the former Schott Applied Power Corporation and the PV module manufacturing of the former ASE Americas. The company has two principal offices, shown in Figure 4. The headquarters in Billerica, Massachusetts, is the location of the PV module manufacturing facility and the product development group. Sales, marketing, and project engineering are in the Rocklin, California, near Sacramento.

Figure 4 RWE Schott Solar, Inc. Headquarters, Billerica, Mass. (left); Sales, Marketing, and Project Engineering, Rocklin, Calif. (right)



Photo Credit: RSSI

The company manufactures and sells the 300 W ASE-300 PV module (Figure 5) and, through the recent merger with Schott Applied Power, now also provides complete photovoltaic system engineering, design, and turnkey PV system installation services.

The systems team has a long history of design and installation of grid-tied PV systems for both pitched-roof residential applications and flat-roof commercial applications. In the early 1990s, company principals pioneered a ballasted mounting system using trays filled with gravel or paving blocks to anchor PV modules at a 25° tilt angle (see photo in Figure 5). This original ballasted design was used successfully to install dozens of small PV systems, between 2 kW and 25 kW, primarily on schools and flat-roof electric utility buildings in many locations around the country. As the market for PV systems on rooftops evolved from research and demonstration projects to a truly commercial market, the need for a lighter and less costly mounting system

became apparent. In addition, the commercial requirements for PV installations became rigorous and PV system designs needed to be fully tested and certified for compliance with commercial building codes.



Figure 5: Ballast-Tray PV Installation in Wisconsin

Photo Credit: RSSI

Building upon the experience gained in the years of research and demonstration with the ballast mounting system, a new design began to take shape. RWE Schott Solar's new Free-Standing PV array mounting system preserves the desirable attributes and features of the original ballast-tray design; however, this project advanced the design of the FS system to meet the more demanding marketplace.

# 1.2 Project Scope and Objectives

The objective of this project was for RWE Schott Solar (RSS) to develop a system that would allow PV modules to be easily mounted on a flat rooftop. Among the desired goals was to eliminate the use of additional ballast materials and to not require any penetrations of the roof for PV array anchoring. In addition, this new mounting system must be low cost, easy to install, modular in design (allowing array increments of any size to be installed) and adaptable to many different roof types and different PV modules. The scope of the contract included:

- Review customer requirements for mounting PV on buildings with flat roofs
- Develop a design and fabricate a prototype that meets the requirements
- Conduct wind force analysis using computational fluid dynamics methods to establish the limits of the mounting system design
- Provide a demonstration of the final mounting system design.

# 1.3 Report Organization

The report is organized into four main sections. The first comprises the introductory and background material. Section 2 identifies and describes the specific tasks undertaken in this contract and Section 3 presents the task results and outcome. Section 4 provides conclusions and recommendations.

# CHAPTER 2: Project Approach

Six tasks were undertaken in this contract. Each is described in the following sections.

# 2.1 Develop Requirements for Mounting System

The objective of this task was to identify and clearly state the functional requirements for the flat-roof mounting system. The approach taken was to build upon our experience and our understanding of the marketplace to help generate a list of requirements.

# 2.2 Develop Design Concept

The objective of the task was to design a PV array mounting system that meets the requirements established in the initial task. The approach was to define a baseline PV system, including modules and inverter, and flesh out the mounting hardware design considering the selection of materials, installation techniques, structural strength, and appearance.

# 2.3 Design Prototype

This task was to fabricate prototypes of the new mounting system components and mock-up a small PV array for initial evaluation purposes. The approach taken was to fabricate the sheet-metal components locally and deploy the prototype on the roof of our offices in Waltham, Massachusetts. This initial prototype and the installation process would serve to help refine the design and lead to further improvement of the mounting system for a second generation prototype.

In addition, this task included the finite element wind loading analysis to determine the limits of applicability of the mounting system.

# 2.4 Reduce Manufacturing Cost

The objective of this task was to reduce the manufacturing costs associated with the new mounting system. The approach was to work with our fabricator to understand the fabrication process and solicit ideas on how to trim cost from the fabricated metal components in the mounting system. This included a review of the materials, tolerances, and features to determine where savings might result without compromising the design and its functionality.

# 2.5 Demonstration Array

The objective of this task was to gain field experience with the installation of the new mounting system to help improve the design. The approach was to deploy a demonstration system in the Sacramento area in cooperation with SMUD. The actual installation methods, time, and costs would be tracked and the lessons learned from the commercial installation would help improve the PV array mounting system design.

# 2.6 Finalize Design

The objective of this task was to finalize the design of the new PV array mounting system. The approach was to refine the design based on the lessons learned from the demonstration array installation experience. In addition, a final design report would be prepared, including a package of materials to support the ready manufacture of the components.

# **CHAPTER 3: Project Outcomes**

The results and outcomes of the six tasks are presented in the following sections.

# 3.1 Design Requirements for Mounting System

It was established that the flat-roof PV array mounting system must meet the following criteria and requirements:

# 1. Penetrationless Design

An overarching objective of this work is to produce a PV array mounting system that does not require penetrating the roof for anchoring to resist the forces of wind. Such a design has many advantages, including lower cost installation, and also is desirable from the standpoint of building owners.

#### 2. Verified and Documented Wind Performance

The penetrationless mounting system must be fully tested and analyzed to ensure its performance in design wind conditions. Documentation from this testing must be suitable for evaluation and approval by professional engineers, and must be adequate for the purposes of obtaining building permits. Testing should include analytic modeling and/or wind tunnel testing, as appropriate and necessary.

# 3. Openings for Air Circulation Cooling

The mounting system design must allow for openings below the PV modules to promote air circulation cooling of the PV modules. Allowing air circulation from all sides below the modules will help maintain array performance, increase module lifetime and promote evaporation of water from the roof.

# 4. Non-Zero PV Array Tilt Angle

The PV modules should have a tilt angle to insure rainwater run-off and some performance gain compared to a horizontal PV array orientation. Higher tilt angles require greater row-to-row spacing and result in increased wind forces. Lower tilt angles reduce row spacing (allowing greater density of PV modules in a given area) and reduce wind uplift forces. The annual energy production should be computed to compare the chosen tilt angle to a horizontal tilt angle and also to an optimal tilt angle for the Sacramento area.

### 5. Adaptability to a Variety of PV Modules

An important attribute of the design is its ability to work with a range of different PV modules. At a minimum this should include the SAPC-165, the ASE-300, and others that may be selected by SMUD.

#### 6. Low Weight

To the extent possible, the penetrationless PV array mounting system should result in an overall dead loading, including modules and all support structure, no greater than 3 pounds per square foot (psf), based on installed PV array area.

#### 7. Low Materials and Installation Cost

Achieving a low cost for installation requires that the system be well engineered to minimize field labor steps. Design attributes that accomplish this should be identifiable. The overall design should result in materials costs for the mounting system hardware of less than \$0.25/Watts direct current (Wdc), stc (dc stc is a commonly used PV industry rating nomenclature that refers to a standard (Standard Test Conditions) that provides a universal comparison basis for PV modules and systems).

# 8. Integrated Design

The mounting system should include features to facilitate array wire routing and junction box attachment.

# 9. Materials Durability

Materials for the mounting hardware, including all fasteners, should be chosen to insure corrosion resistance and durability consistent with a 20-year PV system life.

# 10. Broad Applicability

The mounting system should be applicable to a broad range of roof types found on flat roof buildings in the marketplace. Details of the interface between the mounting system and a range of roof types should be summarized. These interface details should be discussed with roofing manufacturers as necessary to ensure their endorsement of the approach.

#### 11. Serviceability

The mounting system design should facilitate maintenance activity such as the replacement of a damaged PV module.

# 3.2 Design Concept Drawings and Specs

The design took shape based on the criteria that were established in the first task. Table 1 identifies all of the criteria established and how the mounting system concept addresses each.

**Table 1: Comparison of Goals and Actual Design** 

Goals	Status of Current Mounting System Design
Penetrationless Mounting	No penetrations required for the PV array mounting hardware unless, for seismic design requirements, it is necessary to anchor equipment to the structure.
Verified and Documented Wind Performance	Wind performance analysis and wind tunnel testing have been completed. The results support the penetrationless design viability and applicability in the SMUD territory (and beyond).
Openings for Air Circulation	Individual modules, or module assemblies, are supported at four points; all sides and underneath is open for ambient air circulation cooling.
Non-zero PV Array Tilt Angle	Current design is 5-degree tilt angle, measured from horizontal
Adaptability to a Variety of Modules	Mounting system can work with any conventional PV modules, but all things being equal, the economics will favor using higher power modules in panelized form, or a single large-area high power module such as the ASE-300 that does not require panelization.
Low Weight	The weight of materials used in the mounting hardware is minimal and only amounts to approximately 8 pounds per assembly (exclusive of PV modules and panel assembly materials). This translates to 120 pounds of mounting hardware for a 2 kW array, or 216 pounds for a 10 kW array.
Low Materials and Installation Costs	Materials and installation costs for the mounting hardware is quite reasonable.
Integrated Design	The mounting system incorporates features for attaching the company's UL-listed PV source circuit protector, and also pipe nipples to span between adjacent module assemblies for concealing wiring between module assemblies.
Materials Durability	Fabricated mounting system parts are aluminum and fasteners are stainless steel.
Broad Applicability	Discussions with roofing manufacturers indicate that the design is expected to be suitable for all roof types. A neoprene sponge pad acts as a buffer between the base plates of the mounting system and the roof surface.
Serviceability	The mounting system provides walking room between rows of PV modules, both to facilitate installation/wiring and also subsequent inspections and service. It is possible to access all modules in the array easily.

A baseline system with a nominal size of 10 kW (CEC, ac¹) was selected to develop a bill of materials. While systems of smaller and larger size are also of interest, this was chosen as a reasonable starting point for this exercise. The PV modules assumed for this system are the Schott SAPC-165 (165 Wdc, stc) and a Xantrex 10 kW inverter. For the baseline system, the modules would be panelized in groups of three and deployed in three physical rows of 8 assemblies per row. The table below presents a bill of materials for this 10 kW system.

Table 2: Bill of Materials for Baseline System

Item	Quantity
Schott SAPC-165, 165 W PV module with Multi-Contact quick connector cables	72
Custom C-channel panelization rails	48
1/4-20 SS cap screw	288
½-20 SS lockwasher	192
½-20 SS hex nut	1152
Frame wire clips (6 per module)	432
Return cable with Multi-Contact connectors	24
Xantrex 10 kW inverter	1
Transformer for Xantrex 10 kW inverter	1
Base plate	36
Taller fixed jack, plus fasteners	27
Shorter multi-position jack, plus fasteners	27
Neoprene pad for base plate	36
Pipe nipple and two bushings	18
Edge detail bracket	18
PV source circuit protector	3
DC switch, 60 A class, 600 Vdc, NEMA 3R	1

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<sup>&</sup>lt;sup>1</sup> Based on the California Energy Commission calculation that provides a total estimated energy output of a solar system, factoring in the efficiency of the inverter. The California Solar Initiative Program Administrators use the California Energy Commission's CEC-AC method to measure nominal output power of PV cells or modules to determine the system's rating in order to calculate the appropriate incentive level.

Item	Quantity
AC switch, 30 A class, 208 Vac, NEMA 3R	1

Data collected by Miles Russell

# 3.3 Prototype

A prototype of the new mounting system was deployed on the roof of the company's offices in Waltham, Massachusetts. The prototype is shown and described in the pictures that follow.

Figure 6: Three-Module Assembly Using SAPC-165 PV Modules



Photo Credit: RSSI

Figure 7: PV Array Prototype on the Company Office in Waltham, Mass.



Figure 8: View of the Slot in the Support Brackets



Figure 8 shows a close-up view of the slot found in the support brackets. Panel rails are equipped with a mating pin/bolt assembly that slides down and into the slot. A key feature of the design is the dynamic nature of the shorter support bracket. Figure 9 shows how the adjustable sleeve reduces the tilt angle, and therefore the drag, in high wind conditions.

Figure 9: Shorter Support Brackets Have a Sleeve That Can Freely Glide Upward, Positioning the Panels at a Shallower Tilt Angle



# 3.4 Wind Study Results

Wind analysis began prior to this contract, with support from the National Renewable Energy Laboratory. These initial studies were performed assuming a 30-foot tall building. Work was undertaken to expand the wind-force analyses to determine the range of applicability of the FS mounting system. The following situations were considered during this project and the subject of the computational fluid dynamics (CFD) analyses:

- Building heights of 30-feet, 60-feet, and 100-feet
- SAPC-165 PV modules in three-module assemblies, ASE-300 PV modules, and Shell SP-140 modules in three-modules assemblies
- A narrowed row-to-row spacing (prior analyses pre-dated the finalization of row gap to its current ~12-inches)
- The effect of a roof parapet for arrays at roof edge and centered on a roof
- Double and single-row PV arrays.

These different parameters were chosen to provide analysis on a broad range of applications one would expect to encounter in the marketplace. Testing many parameters was intended to identify limits to the design, should they become evident. The results from these analyses are presented in the following sections.

1. Differential pressure at fixed 5-degree and 0.5-degree tilt angles, 90 mph, northwest wind, PV array centered on 120-ft x 200-ft roof, 60-ft building height, no parapet.

Since wind from the northwest was seen to present the worst-case lift situations, results for the northwest wind studies are presented for the remaining case studies. The results show the effect of a 60-ft tall building. In addition, the PV array is based on the ASE-300 PV module for these analyses. Figures 10 (case 6-P4) and 11 (case 8-P4) present the results for northwest wind, large centered array (8 rows of 20 modules, hereafter referred to as 8x20) and tilt angles of fixed 5-degrees and fixed 0.5-degrees. This studied geometry represents what might be specified in a typical 45 kW array.

Results in Figure 11 show the maximum differential pressure of ~80 Pa (pressure differential), well below the 221 Pa required to sustain the pivoted module at its upper limit.

Note: in figures, the line labeled crit is shown for reference and is the differential pressure required to pivot the module to its horizontal orientation. For the ASE-300 this is 221 Pa.

2. Differential pressure at fixed 5° and 0.5° tilt angles, 90 mph, northwest wind, PV array centered on 120-ft x 200-ft roof, 100-ft building height, no parapet.

Results in Figure 12 and Figure 13 illustrate similar conditions but with a 100-ft building height. Figure 13, as before, shows differential pressure well below the 221 Pa required to pivot the module to its shallowest angle.

Figure 10: Pressure Differential, 90 mph, 5° Tilt, Northwest Wind, 60-ft Building, 8x20 Array of ASE-300 PV Modules, No Parapet, Array in Center of 120-ft x 200-ft Roof

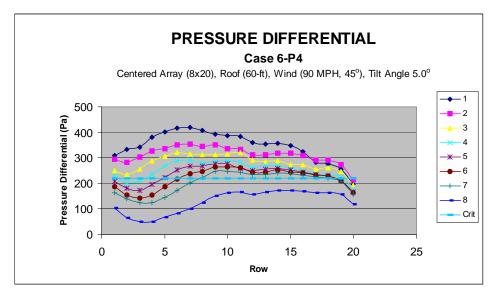


Photo Credit: RSSI

Figure 11: Pressure Differential, 90 mph, 0.5° tilt, Northwest Wind, 60-ft Building, 8x20 Array of ASE-300 PV Modules, No Parapet, Array in Center of 120-ft x 200-ft Roof

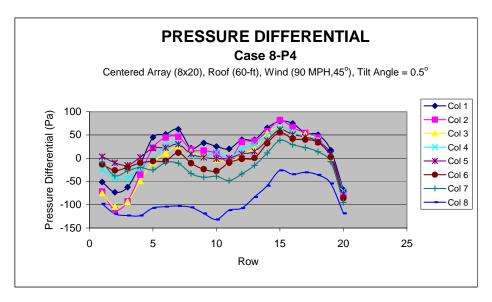


Figure 12: Pressure Differential, 90 mph, 5° Tilt, Northwest Wind, 100-ft Building, 8x20 Array of ASE-300 PV Modules, No Parapet, Array in Center of 120-ft by 200-ft Roof.

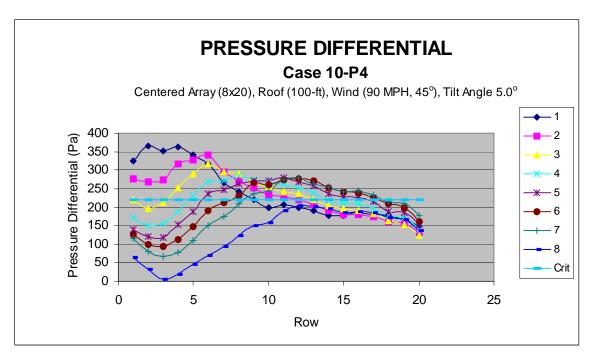
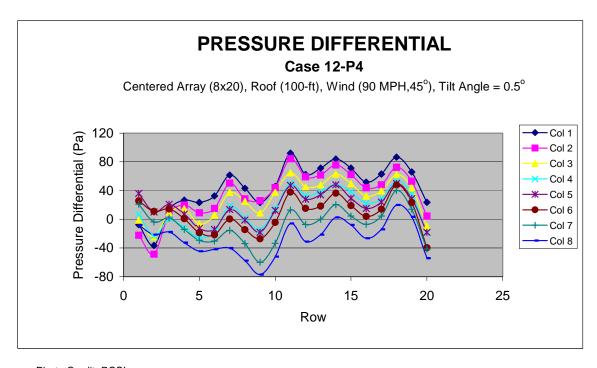


Figure 13: Pressure Differential, 90 mph, 0.5° Tilt, Northwest Wind, 100-ft Building, 8x20 Array of ASE-300 PV Modules, No Parapet, Array in Center of 120-ft x 200-ft Roof.



3. Differential pressure at fixed 5° tilt angle, 90 mph, north wind, PV array at edge of 100-ft x 150-ft roof, 60-ft building height, 30-inch parapet.

A roof with a 30-inch parapet was investigated as a case study. The array uses ASE-300 PV modules in an 8 x 20 layout. In all cases the PV array is located near the building edge at the northwest corner of the roof and the building height is 60-ft. The wind direction is from the north in Figure 14, and from the northwest in Figures 15 and 16.

Note in Figure 14 that north wind is insufficient to create lift at or above the critical value in any modules in the 5° tilted PV array in this scenario. No pivoting would occur. Northwest wind, Figure 14, results in pressure differentials great enough to initiate pivoting in approximately 50 percent of the modules in the PV array. Figure 16 shows that the maximum pressure differential at a fixed 0.5° angle is about 80 Pa, which is insufficient to pivot the modules. As in all prior cases, the wind force is not sufficient to pivot the PV panels to their shallowest tilt angle.

Figure 14: Pressure Differential, 90 mph, 5° Tilt, North Wind, 60-ft Building, 8x20 Array of ASE-300 PV Modules, 30" Parapet, Array at Edge of Roof

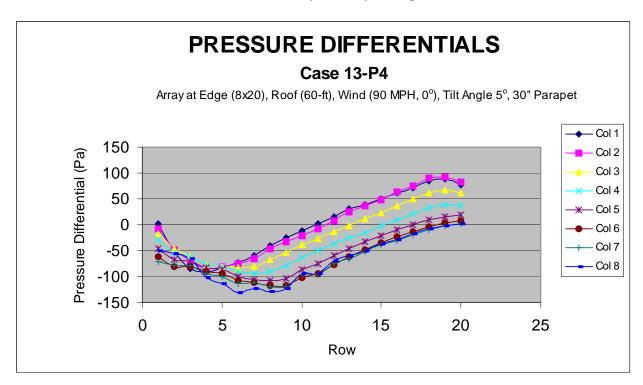


Figure 15: Pressure Differential, 90 mph, 5° Tilt, Northwest Wind, 60-ft Building, 8x20 Array of ASE-300 PV Modules, 30" Parapet, Array at Edge of Roof

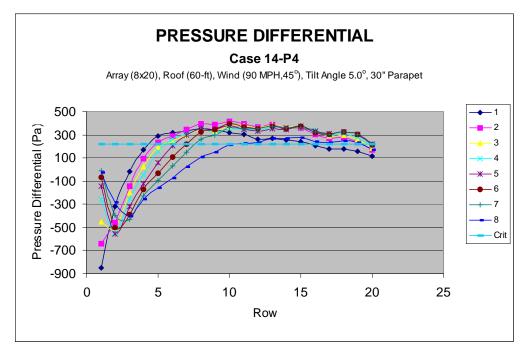
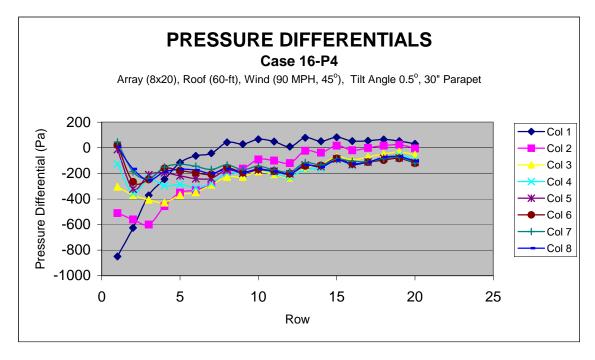


Figure 16: Pressure Differential, 90 mph, 0.5° Tilt, Northwest Wind, 60-ft Building, 8x20 Array of ASE-300 PV Modules, 30" Parapet, Array at Edge of Roof



4. Differential pressure at fixed 5° and fixed 0.5° tilt angles, 90 mph, northwest wind, two-row PV array in center of 120-ft x 200-ft roof, 60-ft building height.

This analysis investigated the forces on a small PV array comprising two rows of 8 ASE-300 PV modules per row. Figure 17 (Cases 26a-P4 and 26b-P4) shows that the differential pressure is sufficient to cause pivoting, but insufficient to force the PV modules to the shallowest tilt angle. Note that a single-row PV array will behave like the northern row of a two-row array.

Figure 17: Pressure Differential, 90 mph, 5.0° and 0.5° Tilt, Northwest Wind, 60-ft Building, 8x2
Array of ASE-300 PV Modules, No Parapet, Array in Center of Roof

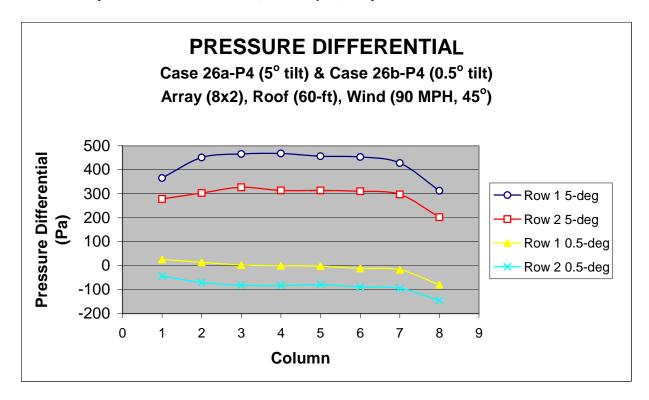
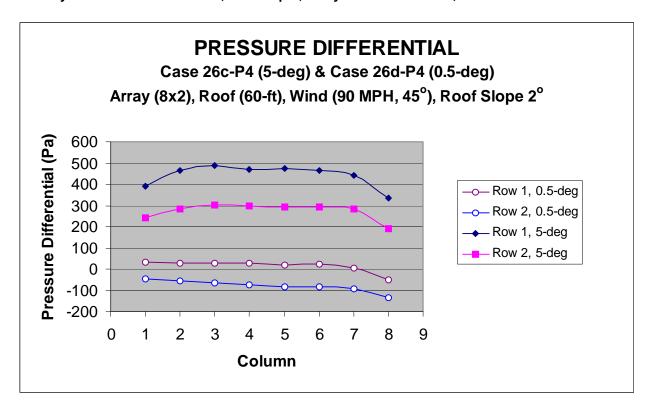


Photo Credit: RSSI

5. Differential pressure at fixed 5° and fixed 0.5° tilt angles, 90 mph, northwest wind, two-row ASE-300 PV array in center of 120-ft x 200-ft roof, 60-ft building height, roof with a pitch of 2° to the south.

This analysis investigated a small two-row PV array of ASE-300 PV modules on a roof with a  $2^{\circ}$  slope to the south. This serves to increase the tilt of the modules relative to horizontal, from  $5^{\circ}$  to  $7^{\circ}$ , and reduce the minimal tilt angle from  $0.5^{\circ}$  to  $2.5^{\circ}$  from horizontal. Relative to the roof the tilt angles remain as before at  $5^{\circ}$  and  $0.5^{\circ}$ . Figure 19 shows the results, which are very similar to those for the flat roof in Figure 18.

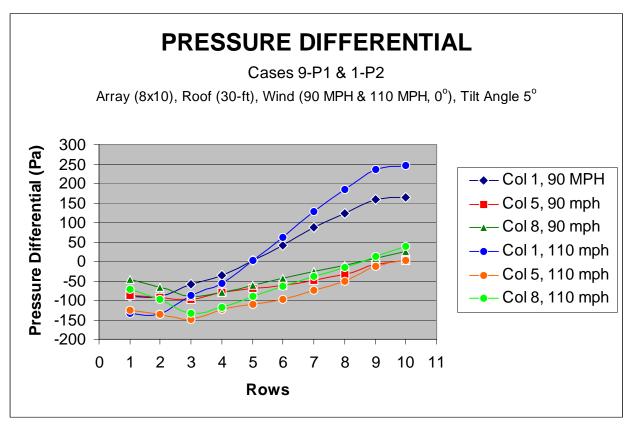
Figure 18: Pressure Differential, 90 mph, 5° and 0.5° Tilt, Northwest Wind, 60-ft Building, 8x2 Array of ASE-300 PV Modules, No Parapet, Array in Center of Roof, with 2° Pitch to the South



#### 3.4.1 Wind Speed Limitations

This section presents a summary of results from all CFD simulations and calculation of the maximum wind speed tolerable by the mounting system. This maximum wind speed is computed based on the scaling laws for the differential pressure calculations. The differential pressure scales very closely to the ratio of the wind speeds squared. For example, differential pressure at a wind speed of 110 mph can be accurately estimated as the calculated pressure value at 90 mph multiplied by  $(110/90)^2$ . To illustrate this, one set of analyses was completed at a wind speed of 110 mph. Figure 19 shows these results. Selecting two points from the figure to make this comparison, note the column 1, row 10 values of 245.0 Pa (at 110 mph) and 164.6 Pa (at 90 mph). Scaling the 90 mph result by the ratio described above predicts a differential pressure at 110 mph of 245.9 Pa, which verifies that the scaling rule clearly holds.

Figure 19: Comparison of an 8x10 Array of SAPC-165 Assemblies, 30-ft tall Building, Array Located at the Roof Corner, Fixed 5° Tilt Angle, Wind Speeds of 90 mph and 110 mph.



The table below identifies the worst-case results across all simulations conducted, for both ASE-300 and SAPC-165 arrays. By scaling the maximum differential pressure values for the 0.5° tilt analyses, so that the pressure equals the maximum tolerable pressure value established in the initial force analysis, the maximum tolerable wind speed can be estimated. These values are shown in Table 3.

**Table 3: Maximum Tolerable Wind Speeds** 

	ASE-300-DG	3-Module SAPC-165 Assembly	
PV array size (modules/row x # rows)	8 x 20	8 x 10	8 x 20
Maximum tolerable pressure, Pa (psf)	221 (4.62)	169 (3.53)	169 (3.53)

	ASE-300-DG	3-Module SAPC-165 Assembly	
PV array size (modules/row x # rows)	8 x 20	8 x 10	8 x 20
Worst case differential pressure at 90 mph, fixed 0.5° tilt angle,			
30-ft building, Pa (psf) 60-ft building, Pa (psf) 100-ft building, Pa (psf)	67.9 (1.42) 82.3 (1.72) 99.4 (2.08)	78.0 (1.63) 	101 (2.11) 127 (2.65)
Scaled wind speed to reach maximum tolerable differential pressure			
30-ft building	162 mph	132 mph	116 mph
60-ft building	147 mph		104 mph
100-ft building	134 mph		

Data collected by Miles Russell

# 3.5 Cost Reduction Results

A top-level bill of materials for the new mounting system shows that there are five main components, as follows:

- 1. Panel assembly rails
- 2. Tall RoofJack
- 3. Short RoofJack
- 4. Base plate
- Lock plate

Each of these components is actually an assembly of several parts, including custom fabricated pieces and other items like fasteners that are off-the-shelf. Addressing the overall cost of these items included consideration of the parts suppliers, price/volume sensitivity, and also consideration for who could do the assembly associated with these components the most economically. Figure 20 shows the relative contribution of each of these five main components to the total mounting hardware BOS cost for an example 30 kW PV system.

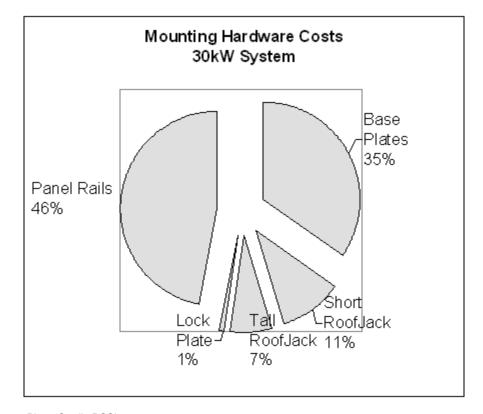


Figure 20: FS Components Cost Comparison

# 3.5.1 Panel Assembly Rails

As shown in the pie-chart, panelization rails make up the largest cost component in the mounting hardware BOS materials for the 30 kW PV system. This chart shows only the materials and not the assembly labor or shipping costs associated with the actual panelization of the modules. Panelization of three SAPC-165 modules takes approximately 0.5 man-hours per assembly. If this were done in a centralized location, all assembly steps could be conducted in a controlled environment by properly trained and experienced individuals, with all jigs, tools, and supplies. This is the preferred approach; however, creating large panel assemblies would require development and handling of crates to ship these large assemblies by truck, and both personnel and shop space to deal with these large, heavy assemblies properly. Alternately, panelization can be local to the job site. This may be at the installer's shop, at the customer's site, or even on the roof of the building where the array will be located. On-site panelization avoids the shipping and crating concerns, but field work is typically more costly and less easily controlled than shop work. Field panelization also introduces the requirements to find space where such assembly can take place on site, bring crews in to do the work, and test and store the assemblies until installation takes place. While this situation is not fully resolved, it seems abundantly clear that using the ASE-300 large-area PV module, which requires no panelization, would avoid the issues entirely and thereby offer advantages in the overall system installation process.

Panelization rails are custom-fabricated aluminum C channels with holes for securing the PV modules, two pressed-in stainless steel ¼-20 threaded nuts for ground lug attachment and the mounting pin assemblies installed at both ends of the rail. To reduce cost of the panelization rails, our fabricator is now taking responsibility for ordering, stocking and installing the mounting pin assemblies. Previously the ordering and stocking of these small parts, and the attachment of the pins to the rails, was done by RWE SS staff less efficiently and at a greater cost. The rail is fabricated with a folded-over tab at the very ends, with a stud pressed in the tab's center. The stud is used to form the mounting pin assembly, requiring a single ¾-inch diameter stainless steel flat washer, an aluminum ferrule (short length of aluminum tube) and a stainless steel ¼-20 stopnut. The aluminum ferrule is available as an off-the-shelf item for approximately \$0.36 apiece, but our fabricator is looking into making these by cutting aluminum tube to reduce cost further. The rails are now provided in a ready-to-panelize form from the fabricator, reducing the company's handling costs and eliminating the aforementioned small parts ordering and assembly issues.

#### 3.5.2 Base Plates

The base plates are made of stainless steel to provide the modest additional ballast needed to ensure a comfortable margin of safety for design wind loading conditions. Prior to establishing this solution to the ballast question, the base plate prototypes were made of aluminum and the ballast was assumed to be field-supplied concrete blocks or bricks of appropriate weight. The design team opted for the cleaner and simpler solution, with stainless steel base plates and no additional ballast, although this was knowingly adding to the overall cost. As in the pie chart, the base plates are the second largest contributor to the overall cost of BOS materials in this new mounting system. The company determined that the benefits of the stainless steel base plate outweighed the modest increase in the cost of the product. The benefits of stainless steel are that no additional ballast is required and the shorter RoofJack slides more easily over the stainless steel surface as it is moved into its final position. Galvanized sheet steel is less expensive than stainless steel, has equivalent density/weight and is a possibility. However, galvanizing is a surface treatment and it does not guarantee long-term protection from oxidation. In fact the authors have a great deal of experience with the weathering of galvanized sheet metal and have observed rust formation occurring after only a year of exposure. In addition all cut edges of galvanized steel sheet metal must be coated or they will rapidly oxidize. With a secondary surface treatment required to insure longer-term durability, the cost advantage of galvanized steel rapidly disappears and the durability of this material otherwise is just too poor to be a part of our high-quality design.

The base plate is presently made from two sheets of 0.090-inch thick stainless spot-welded together. The top plate has four stainless-steel threaded 5/16-18 studs pressed in that are used by the tall and short RoofJacks. A ¼-inch thick neoprene pad is adhesively attached to the bottom of the base plate. To reduce cost of this component and its assembly, RSS is now having our fabricator take responsibility for purchasing, stocking and applying the neoprene pad to the base plates. This keeps company personnel out of the process and replaces them with lowerwage labor at the fabricator's shop. It also eliminates this as an on-site assembly task.

Standardization is another way to help increase purchasing volume, obtain better prices as a result and also reduce the number of parts the company stocks. The base plates must be designed to work with at least these three PV modules: the SAPC-165, Shell SP140 and ASE-300. Since the base plate controls row-to-row spacing of modules, it must be designed to maintain the proper dimensions for these modules across a wide range of site latitudes, with row-to-row shading and overall array packing density being the two competing design considerations. The company is presently evaluating whether one base plate can serve both the Shell and SAPC modules (since they have nearly the same up-slope dimension), and a second version used for the ASE-300 with its much shorter up-slope dimension. The more difficult question is whether RSS needs two or more versions of the base plates to allow different row spacing, based on the site latitude. This question boils down to analysis of row-to-row shading and its effect on annual energy production (annual kWh/kWac,cec) and the effect of row spacing on overall array packing density (kWac,cec/square foot). These are two linked metrics that can be assessed to determine a reasonable solution.

#### 3.5.3 Short RoofJack

This component is in the third place as far as its cost, at 11 percent of the total. This component is the heart of the design and it contains many important features. The basic design is the result of several iterations and neither the design nor materials will be altered without careful consideration and feedback from the field. However, RSS is now realizing some small savings by relying on our fabricator to source and install the small fasteners and aluminum ferrule that are part of this assembly. The short RoofJack arrives from our fabricator ready to be installed on the base plates, with no further assembly required.

# 3.5.4 Tall RoofJack

The tall RoofJack is a simpler piece than the short RoofJack and accounts for only 7 percent of the cost of the mounting system BOS materials. Minor steps are being taken to reduce RWE SS labor content in the shop or field by relying upon the fabricator to do a greater amount of assembly work in the shop. In the case of the tall RoofJack, the fabricator will be installing a PVC pipe nipple with nuts and bushings. This is a nuisance step if left for field work and is far more efficiently done by the fabricator prior to shipment to the field or the Rocklin office. In addition, the fabricator will be securing a grounding lug to the tall RoofJack, again to eliminate the need for securing this in the field. No changes to materials or physical dimensions are under consideration at this time.

#### 3.5.5 Lock Plate

The final piece of hardware in this mounting system is the so-called lock plate. These are used only on the northern-most and southern-most rows of an installed array, where the base plate is turned 180° to reside beneath the modules, rather than sticking out from them. The turned base plates then disappear from view, leaving a very clean and finished-looking overall PV array. The lock plate connects the turned base plate to the one in the adjacent row. No changes are planned to this component and it does not require any assembly.

# 3.5.6 Mounting Hardware Relative Cost in System

To see the relative cost of this mounting system, it is shown as a percentage of the total cost for a 30 kW system installation in the chart below. The categories contributing to the total in this chart include reasonable estimates and actual costs for all elements. Installation costs are something RSS will be refining further, as the company gains experience with the deployment of the new mounting system. The obvious conclusion from this chart is that modules dominate all cost categories, followed by installation labor. The other four components are all much smaller contributors and roughly equal in terms of their cost. In terms of leverage, the installation of the equipment is where the greatest return on an investment in optimization could be made. As RSS gains more experience with the new mounting system, the company will be focusing on ways to streamline the installation process.

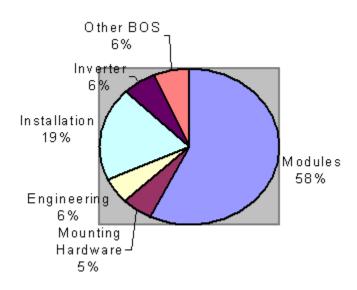


Figure 21: Cost Elements in a 30 kW PV System

Photo Credit: RSSI

# 3.5.7 The Effect of Quantity on Cost

Our fabricator has provided quotations on various quantities to aid us in planning for production of the new mounting hardware components.

Volume Cost Reduction Percent of qty 30 Cost 120.0% 100.0% ■ Tall RoofJack 80.0% ■ Short RoofJack 60.0% ■ Base Plate ■ Lock Plate 40.0% Panel Rail 20.0% 0.0% 30 1000 2000 500 **Fabrication Quantity** 

Figure 22: Effect of Production Quantity on Relative Cost of FS Hardware Components

Clearly and predictably, the more pieces fabricated at one time, the less the pieces will cost. All but the base plate see a 20 percent drop in cost going from the 30-piece production run, a quantity appropriate for prototyping and testing, to a more reasonable production quantity between 500 pieces and 2,000 pieces. Accordingly, RSS is planning a blanket fabrication order on the order of 1,000 pieces to 2,000 pieces, to ensure a stable supply and reduced price.

# 3.6 Demonstration Array

This section documents the demonstration PV array using the new FS mounting system. The 30 kW demonstration PV array was completed in mid-August 2003 and is located on a retail furniture store in Rancho Cordova, California, approximately 10 miles east of Sacramento, California. Photos of the system and lessons learned are included below.

# 3.6.1 System Specifications

Open-Circuit Voltage, stc

The PV system installed on the La-Z-Boy retail furniture store in Rancho Cordova, California, has the following specifications:

	Module	Source Circuit	Subarray	Array
Description	SAPC-165	12 series	6 source circuits, 72 modules	3 subarrays, 216 modules

43.1 V

Table 4: Specifications for the Demonstration PV System

517.2 V

517.2 V

517.2 V

	Module	Source Circuit	Subarray	Array
Max-power Voltage, stc	34.6 V	415.2 V	415.2 V	415.2 V
Max-power Current, stc	4.77 A	4.77 A	28.6 A	85.8 A
Short-circuit Current, stc	5.46 A	5.46 A	32.8 A	98.4 A
Maximum Power, stc	165 Wp	1,980 Wp	11,880 Wp	35,640 Wp
Rating, CEC, dc	144.8 W	1,738 W	10,426 Wp	31,277 Wp
Rating, CEC, ac				30,026 Wac

Data collected by Miles Russell

#### 3.6.2 Lessons Learned

The La-Z-Boy site is typical of real-world rooftops, that is, there were obstructions to work around on the roof and the array has several broken rows. In addition there were significant issues relating to meeting seismic design requirements that the authors spent a great deal of time and effort to address, and are described in this section.

#### 3.6.2.1 Site Assessment

Two large HVAC cabinets and a small satellite dish TV antenna were three of the objects on the roof that had to be worked around. This is not necessarily a problem, nor new, but it points to the critical importance of having an accurate roof plan available when finalizing the system configuration and layout plan. The required site assessment information also includes the height above the roof deck for all equipment and obstructions. RSS has tools for assessing how far away to position modules from such obstructions, based on their height and site parameters. The challenge in array layout on roofs like the La-Z-Boy store is to avoid module shading but maintain logical groups of modules to form source circuits without overly complicating array wiring. The lesson learned is a reminder to map roofs accurately and thoroughly, and also that the FS array's mechanical sharing and linking of components facilitates working around gaps.

Figure 23: FS Array Can Accommodate Gaps While Maintaining the Mechanical Linking of All Components.





# 3.6.2.2 Array Layout Procedure

RWE SS hired a local contractor to complete the array installation. The contractor had no prior experience installing an FS array, but the crew was provided with a demonstration of the FS at the Rocklin California office of RWE Schott Solar to introduce them to the basic design. Of great interest to us is how FS novices, experienced with roof work and solar installations, would elect to measure, mark, and install the FS baseplate assemblies. This process was complicated by the broken rows, necessary to avoid the objects on the roof. The contractor defaulted to the same procedure that our own staff settled on at an

earlier FS installation, that being chalk lines and a tape measure. This seems to be quick and convenient as these are common tools and procedures, and easy to work with. Our own experiences with a custom template proved it to be clumsy and slow. However a simple template may still be advantageous on much larger arrays and remains something to be further considered.

One important lesson in array layout was in regard to maintaining proper spacing of baseplate assemblies across a gap, for non-continuous rows of modules, such as the ones seen in the vicinity of the HVAC cabinets and antenna. To ensure that the proper spacing was maintained, the contractor actually installed the PV assemblies and base plates across the gap (this area would be in the shadow of the antenna equipment) to make a complete row. Then, once the module row to the south was installed, they removed the modules in the shadowed gap. This was done for the split rows north of the satellite antenna in Figure 24. The lesson learned is that a logical procedure for array installation should be provided, tailored to the specific project, and include where to start and how to negotiate gaps.



Figure 24 Discontinuous Rows North of Satellite Antenna

#### 3.6.2.3 Permit Process

The permitting of the system on the La-Z-Boy store consumed a great deal of time, as various issues came up and were addressed. The first issue that presented itself was the wind analysis. A growing body of engineering data has been generated from the multifaceted analyses undertaken by the company over the past year regarding the wind forces on the FS array. This body of data includes the basic force balance, the wind tunnel results and the extensive computational fluid dynamics work. The sum of this information makes a compelling case for the wind resistance of the FS array. Clearly it is not reasonable to expect that building departments would be willing, interested or able to absorb the engineering details of the wind analysis work that was conducted on the FS array. Instead it is standard procedure to have such material reviewed by a professional engineer who in turn provides a letter certifying that the design meets all required codes. Toward that end the authors sought to identify a professional engineer who could review the wind analyses documentation and provide such certification of the design. This exercise led us down several blind alleys, working with engineers who either could not or would not follow through on the work, before finding the right firm.

WD Partners, the firm RSS selected, is located in Ohio but has engineers who maintain their registration in every state in the union. This is an incredible advantage as it means that RSS does not need to repeat the exercise every time the company wants to install FS systems in a new state, such as Massachusetts, New Jersey, or New York. RSS provided WD Partners with the comprehensive summary of the wind analysis work, and spent time in discussion with their engineers about the wind tunnel testing and the CFD analyses. The engineers spoke separately with the CFD contractor about the analyses to gain further understanding of this work and the results it generated. Finally the engineers were satisfied that the design had undergone rigorous testing and evaluation and met all requirements of the ANSI ASCE7-98 code for wind resistance. A stamped letter from WD Partners for California was obtained in early June.

The next hurdle toward getting a building permit was the issue of the seismic requirements in California. Building codes do not recognize friction as a means of resisting seismic forces, which required that RSS develop one or more solutions to anchor the FS arrays. Three possibilities were considered: tethering with cables, adhesive bonding, and mechanical anchoring. Of these, the most benign and least expensive is adhesive bonding. The concept is that the baseplates around the perimeter of the installed array would be adhesively bonded to the roof. This concept was reviewed with the professional engineers at WD Partners who were asked to provide a letter certifying the design and its compliance with the seismic requirements in the code. Their analysis of this approach concluded that half of the perimeter baseplates should be bonded to the roof. WD Partners provided a stamped letter certifying the bonding approach in early June.

The identification of this engineering firm and the completion of both the wind certification and seismic certification are huge accomplishments that will greatly streamline the permitting of FS arrays.

# 3.6.2.4 Adhesive Bonding of Baseplates

In order to meet the building code requirements for withstanding seismic forces, RWE SS developed a tie-down solution involving bonding every other perimeter baseplate to the roof deck. This basic approach was reviewed and approved by WD Partners, professional engineers, who provided a stamped certified letter regarding this method and its compliance with the code. The La-Z-Boy site is the first installation where baseplates have been bonded in this way.



Figure 25: Standard Baseplate With Neoprene Pad

Photo Credit: RSSI

The baseplates normally come with a ¼-inch thick neoprene pad on the bottom side. Those baseplates around the perimeter that were adhered had no neoprene. Instead these baseplates were seated on a slipsheet of rolled roofing, the same as the roof covering material. The slipsheet was adhered to the roof using typical mastic and the baseplate was adhered to the slipsheet using ChemLink M-1 adhesive. The procedure was that after the array was installed, the baseplates to be adhered were marked. The outline of the baseplate was marked on the roof and the modules removed and baseplate set aside. The slipsheet was cut to a size a little larger than the baseplate and secured to the roof. The baseplate was returned to its place and its outline marked on the newly installed slipsheet. Finally the baseplate was removed again, the adhesive applied and the baseplate placed back into position. The bonding worked well and presents a clean finished appearance on this roof.

Figure 26: Slipsheet Bonded to Roof Material

#### 3.6.2.5 Installer Techniques

Having never before installed an FS array, the contracted crew was cautious at every step. They were provided with photographs of the modules and panel assembly, the combiner box, the taller and shorter jacks and baseplates, as part of their training and installation materials. They made copies of these and taped them to various sections of the array as the installation proceeded to confirm that all components were oriented properly and also to show how wiring was done. This was a clever way to remind the crew of these details without requiring thumbing through a manual or text.

#### 3.6.2.6 Recommendations From Installers

The installers made the following suggestions for future FS array installations:

- When assembling the taller RoofJack, the bushings on the pipe nipple should set the separation of the two vertical legs of the RoofJack, and the locknuts should be spun out to maintain that separation.
- Instructions should explain that the pipe nipple must be removed from the taller RoofJack when a PV source circuit protector (PVSCP) is secured to the jack.
- Instructions should explain that when building the mechanical assembly of three SAPC-165 PV modules, the outer modules should be justified to the end of the panelization rails, so the rails are flush with the module frame. The middle module should be centered, leaving a small gap on both sides.
- A note should appear on the assembly instructions to slide the shorter RoofJack all the way to the north and leave it finger-tight. When the baseplates are placed

into position, the panel assemblies will then drop right into the shorter RoofJacks.

• The plan view PV array layout drawing should depict and identify the three different styles of baseplate assemblies: north, south, and middle. The quantity of each should also be identified on the drawing.

#### 3.6.2.7 Wiring of Non-Contiguous Module Groups

Field wiring between panel assemblies to form a source circuit is straightforward when the 12-module groups are continuous. Assemblies of modules plug together and terminate at a PV Source Circuit Protector (PVSCP) that would be mounted in between two adjacent source circuits. The situation where a source circuit is formed from separated groups of modules, as in the La-Z-Boy array, requires that the wiring from one row be connected to another row to form a source circuit. The crew at this site chose to strap a short length of PVC conduit between the taller RoofJack on one baseplate to the shorter RoofJack on the next, as shown in the figure below. A jumper with multicontact quick connectors on each end is routed through the conduit sleeve and mates to the two PV assemblies, wiring them in series. The connector cable from the northern assembly emanates from the upper edge near the taller RoofJack. The jumper cable connects there and is routed underneath and clipped to the module frame, down the length of the module, past the lower RoofJack and looped back to go into the conduit. This leaves a length of cable near the lower RoofJack that could at some future time become disengaged from the frame and dangle below the module. This would present the potential for the cable to become snagged inadvertently or to interfere with the movement of the lower RoofJack in a high wind event, or in any case look unsightly. Far better would be for the conduit to be three feet longer and extend from tall RoofJack to tall RoofJack. This is the lesson learned and should be included in site-specific instructions where broken strings are found.

Figure 27: PVC Conduit Secured Between RoofJacks Protects Wiring Jumper From One Row to the Next



# 3.6.2.8 System Cost

Project costs are carefully tracked. The chart below shows the balance between major cost elements for the demonstration system. The FS hardware comes in at about 5 percent of the total. While this is quite low, the authors have efforts underway to look for near-term and long-term possibilities for further cost reduction of this hardware. Note also that installation was quite low for this project, owing to a very competitive bid from the chosen contractor.

FS System Price Summary

10% 5% 6%

10% □ FS Hardware
□ Other BOS
□ Inverter
□ Modules
□ Installation

Figure 28: System Component Costs as Percentage of the Total

# 3.9.6.9 Data Acquisition System and Performance Results

The La-Z-Boy demonstration system is equipped with a SunTrack<sup>™</sup> data acquisition system that monitors and records the following system parameters:

- Plane-of-array irradiance (sunlight intensity on the surface of PV modules)
- Ambient air temperature
- Wind speed at the level of the array
- AC power from the PV system (obtained from a kWh meter with pulse output for automated recording)

The data from the PV system are archived in 15-minute interval bins accessible over the Internet. Remote monitoring of the system has been an effective way to detect problems that occur. For example, in September 2003 a circuit breaker was accidentally tripped, knocking the system off-line. Following are records of generation from the 30 kW PV System for the months of October and November 2003. The PV system produced 2,614 kWh in October. The onset of rainy winter weather and lower sunlight levels reduced the PV system output to 1,900 kWh in November. Figure 30 shows a representative daily profile of meteorological data, including wind speed (mph), sunlight (W/m²), and ambient air temperature (°F).

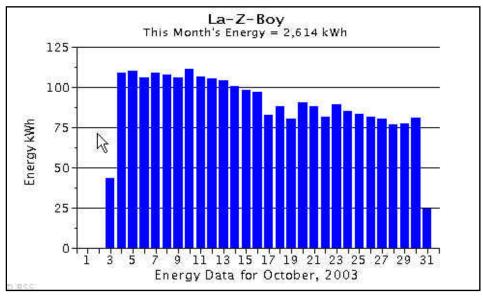


Figure 29: October Daily Energy Generation

Figure 30: November Daily Energy Generation

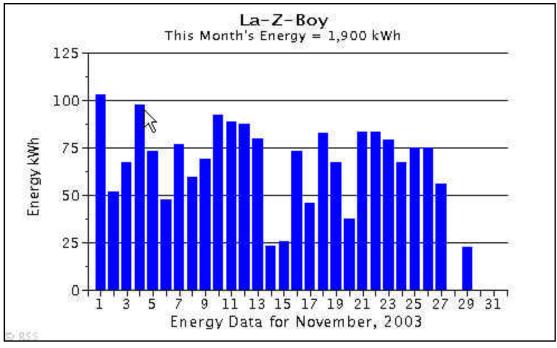
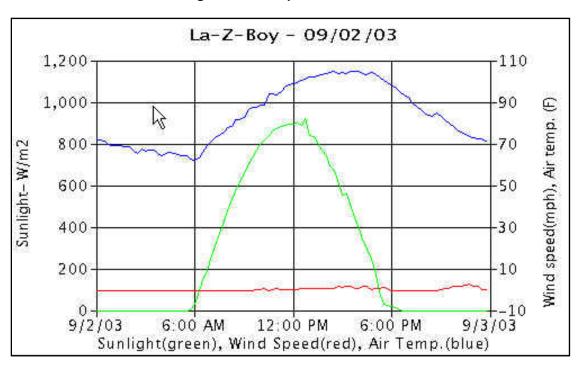


Figure 31 Example Weather Data



# 3.6.3 Demonstration System Photographs



Figure 32: Panel Assembly On-Site

Photo Credit: RSSI



Figure 33: Weather Sensors Attached to Taller RoofJack

Figure 34: Baseplate and RoofJacks at Interior Corner With Clear Space Provided Around HVAC Equipment



Figure 35: Electrician's Temporary Shelter



Figure 35 shows the temporary shelter that the electrician created to provide shade while he worked in the area where the inverter and associated transformer and switches are located. He also had a fan and water mist sprayer. Temperatures were in the mid-to-high 90s.

Figure 36: AC Wiring in Conduit Penetrating Roof to Connect With Electrical Cabinet Inside



Photo Credit: RSSI

Figure 37: AC Output of the PV System Is Connected to the Grid in the Electrical Room



# 3.7 Final Design

This section describes the final design of the penetrationless PV array mounting system engineered, tested and brought to market by RWE Schott Solar Inc. (RSSI) over the past 18 months. Included in this section are:

- 1. Description of the mounting system and its components.
- 2. Seismic compliance work.
- 3. Application guidelines.
- 4. Permitting process.
- 5. Cost information.

# 3.7.1 Description of the FS Mounting System

The penetrationless free-standing (FS) mounting system is shown in Figures 39 and 40. These figures show plan and elevation views of an example FS PV array using ASE-300 PV modules and the FS mounting system components are identified. Note in the figures the four basic components of the mounting system: the PV module or module assembly, base plate, taller RoofJack, and shorter RoofJack. These components are further described below.

# 3.7.1.1 PV Module or Module Assembly

The mounting system is designed to work with the ASE-300 large-area PV module (300 Wdc,  $74.5'' \times 50.5''$ ), as well as assemblies of typical 140 to 165 W PV modules, such as the SAPC165 and Shell Solar SP140/150. Whether used with the large module or a module assembly, the panel must be equipped with the standard RWE SS mounting pin assembly (see detail below). Figure 38 illustrates the mounting pin assembly affixed to the frame of the ASE-300 PV module.

ASE-300 PV
MDDULE LAMINAT
DDUBLE GLASS
CINSTRUCTION

ADHESIVE TAPE
EDGE PROTECTION
EDGE PROTECTION
ASSEMBLY, ST
STEEL

PERIMETER FRAME
MILL FINISH ALUMIN

ADMINING PIN ASSEMBLY, "A"
2 PLACES BOTH ENDS

Figure 38 ASE-300 PV Module and Mounting Pin Assembly Detail

Figure 39: V Array Plan View Layout Illustration With ASE-300 PV Modules

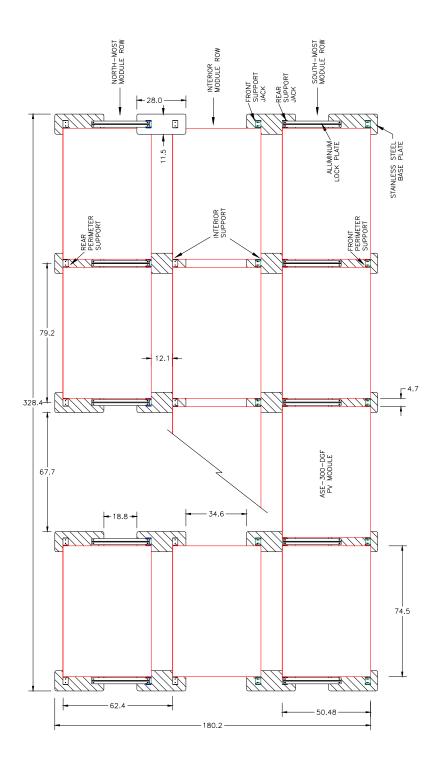
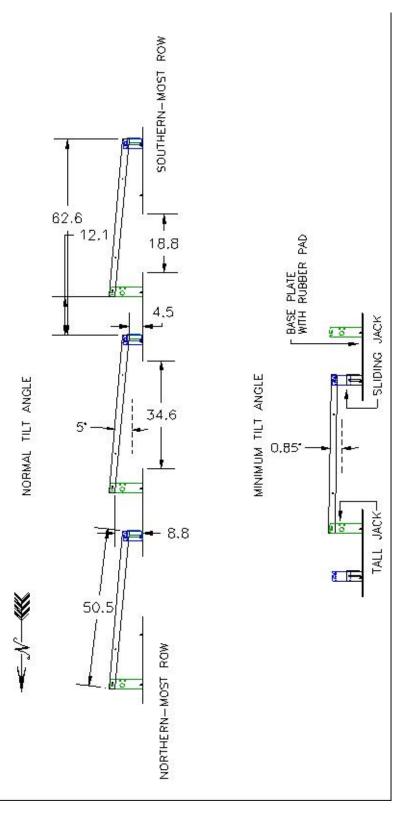


Figure 40: Elevation Views of ASE-300 PV Array at Initial 5° Tilt Angle and at Rully Wind-Relieved 0.85° Tilt Angle



#### 3.7.1.2 Base Plates

The rectangular stainless steel base plate is shown in Figure 41. The base plate's longer dimension differs with the module type being installed, as shown in Table 5.

**Table 5 Baseplate Specifications** 

	PV Module Type		
Parameter	ASE-300	SAPC-165 x 3	Shell 140 x 3
Base Plate dimensions	11.5" x 28.0"	11.5" x 38.0"	11.5" x 38.0 "
Base Plate area	2.24 sq. ft.	3.0 sq. ft.	3.0 sq. ft.
Loading (average for middle row position includes module(s) and baseplate with jacks)	55.8 psf	52 psf	52.4 psf

Data collected by Miles Russell

A ¼-inch thick pad of sponge neoprene rubber is adhered to the bottom side of the base plate. Plate corners are rounded. Stainless steel 5/16-inch diameter threaded studs are pressed into the base plate at both ends during fabrication. The taller and shorter RoofJacks are secured to these studs, as described below.

Figure 40 Top and Bottom Views of Base Plate





The base plates rest directly on the building roof surface or on an approved interface material, depending on the specific roofing system and requirements where installed. The plates are laid out in rows and columns as required for the size and geometry of the PV array to be mounted. The base plates define a fixed separation between PV module rows and also link together mechanically all the modules within the PV array.

#### 3.7.1.3 Taller RoofJack

The taller RoofJack bolts to one end of the base plate. This RoofJack is equipped with three defining features: the mounting pin slot, large holes for a PVC pipe nipple used as a wiring pass-through, and the smaller holes for attachment of the company's UL-listed wiring junction box. The taller RoofJack supports one end of the PV module assembly as shown in Figure 42 below. The RoofJack is shared by adjacent panel assemblies at all internal positions within the PV array.



Figure 41 Taller RoofJack Supporting an Assembly of SAPC-165 PV Modules

Photo Credit: RSSI

#### 3.7.1.4 Shorter RoofJack

The shorter RoofJack, Figure 44, attaches to the opposite end of the base plate. As seen in the drawing of Figure 39 and the photo in Figure 43, the PV assembly spans from the taller RoofJack on one base plate, to the shorter RoofJack on another base plate. In fact, a PV module assembly is supported by RoofJacks on four separate base plates. Similarly, each baseplate

internal to an array (not one of the baseplates around the perimeter) supports a corner of four different modules or module assemblies.

Figure 42: View of Baseplate With Both Roofjacks Supporting PV Module Assemblies



Photo Credit: RSSI

Figure 43 Shorter RoofJack with Sliding Supports



The shorter RoofJack consists of three pieces: two identical vertical sliding pieces, with the L-shaped slot for the mounting pin assembly, and the U-shaped base that secures the bracket and provides guides for the travel of the vertical sliding pieces. Note that the base of the shorter RoofJack has slotted holes where it attaches to the studs in the base plate.

A PV module assembly is lowered into the L-shaped slot of the taller RoofJack (Figure 42) and slid forward until the mounting pin rests at the bottom of that slot. The lower end of the PV module assembly is then dropped into the L-shaped slot of the shorter RoofJack (Figure 44) and this RoofJack is slid back on the base plate (using the slotted mounting holes) and tightened into position, trapping the mounting pins of the PV assembly. This prevents the PV assembly from being removed from the mounting brackets without the use of a tool.

# 3.7.1.5 Theory of Operation

The function of the shorter RoofJack is to support the lower end of the PV module assembly and provide for the free, limited upward movement of this trailing edge of the PV module assembly as a means to limit upward forces on the PV assembly under design wind extremes. As wind speed increases and forces tending to lift the shallow-tilted PV assembly grow, the vertical sliding elements of the shorter RoofJack are free to glide upwards in the bracket, to maintain a balance between the wind uplift forces and the dead load of the PV module assembly. The PV module assembly begins at a nominal 5° tilt angle measured from horizontal. With wind from any northern direction, a PV module assembly can experience uplift forces that are counteracted by the dead load of the PV modules and associated mounting hardware. The sliding supports of the shorter RoofJack allow the PV module to pivot at the support point of the taller RoofJack and rotate upward to a shallower, near-horizontal tilt angle, as needed to balance the vertical components of forces on the PV modules. The ultimate effect of this feature is to limit wind uplift forces on the PV module assembly.

#### 3.7.2 Issues and Their Resolution

#### 3.7.2.1 Wind Analysis Certification

Upon review of all the wind analysis data, including the basic force analysis, the wind tunnel testing, the many different computational fluid dynamics analyses, and the validation of the CFD method with the wind the tunnel results, WD Partners, a professional engineering firm, has provided a stamped letter certifying compliance of the FS mounting system with ASCE 7-98, Minimum Design Loads For Buildings and Other Structures. At present RSS has certification letters from WD Partners for the FS mounting system in California, Massachusetts and New Jersey. When the need arises to work in other states, the company can obtain the necessary stamped certification letters from the same engineering firm, as they maintain professional licenses in all 50 states! The stamped wind certification letter for California is included at the end of this report.

# 3.7.2.2 Seismic Design Requirements

The Uniform Building Code disallows the consideration of friction to counteract the sliding and overturning forces resulting from seismic activity for roof-located equipment such as a PV array. Accordingly RSS has developed what the authors believe is the preferred solution to secure the FS mounting hardware to a roof in seismic zones where this is an important design

issue. The three approaches RSS explored were: adhesively bonding the baseplates to the roof, tethering the perimeter module rows and columns with cables anchored to the structure, and anchoring the baseplates to the structure in a traditional manner by bolting through the deck to the structure below. The simplest of these by far is the adhesive approach. With assistance from a professional engineering firm, a solution was established that involves bonding 50 percent of the baseplates around the perimeter of an installed PV array to the roof surface. The engineering firm provided us with a stamped letter (appended) certifying that this method satisfies the Uniform Building Code for seismic zone 3 and zone 4, which covers all of the state of California.

The adhesive bonding method was tried for the first time at the demonstration PV array site at the La-Z-Boy furniture gallery in Rancho Cordova, California, which provides an example of how this attachment scheme is implemented. The baseplates normally come with a ¼-inch thick neoprene pad on the bottom side (Figure 45). Those baseplates around the perimeter that were adhered had no neoprene. Instead these baseplates were seated on a slip-sheet of rolled roofing, the same as the roof covering material (Figure 45). The slip-sheet was adhered to the roof using typical mastic and the baseplate was adhered to the slip-sheet using ChemLink M-1 adhesive. The procedure was that after the array was installed, the baseplates to be adhered were marked. The outline of the baseplate was marked on the roof and the modules removed and baseplate set aside. The slip-sheet was cut to a size a little larger than the baseplate and secured to the roof. The baseplate was returned to its place and its outline marked on the newly installed slip-sheet. Finally the baseplate was removed again, the adhesive applied and the baseplate placed back into position. The bonding worked well and presents a clean finished appearance on this roof.

Figure 44: Standard Baseplate With Neoprene Pad (left) and Slipsheet Bonded to Roof Surface (right)



Photo Credit: RSSI

A modified approach is also being investigated. Instead of bonding the baseplate to a pad that is bonded to the roof, the authors are exploring bonding a separate bracket on a pad directly

behind a baseplate that must be secured. This bracket, adhesively bonded to the pad, would be designed to fasten mechanically to the baseplate's threaded studs, to secure it in place. This leaves the baseplate free to be moved, should that ever be necessary or desirable. Even more important, however, this approach to securing the array perimeter can be completed after the array is installed and without disturbing the installed modules and mounting hardware.

# 3.7.3 Application Guidelines for the FS System

Summarizing from these results and including margins of safety, following are the recommended guidelines for application of the FS system.

3.7.3.1 Applies to All PV Arrays - Part I

**Table 6: Maximum Recommended Design Wind Speeds** 

Maximum Recommended Design Wind Speed (3-sec gust, mph)			
Building Height (ft.)	ASE-300-DG	SAPC-165 x 3	Shell-140 x 3
30	130 mph	110 mph	110 mph
60	130 mph	100 mph	100 mph
100	120 mph	90 mph	90 mph
>100	Contact RWE SS (custom analyses may be required)		

Data collected by Miles Russell

#### 3.7.3.2 Applies to Arrays on Sloped Roofs Not in Seismic Zone 3 or Zone 4

If PV arrays are not in seismic zones 3 or 4, or if installations are not subject to seismic design requirements and approvals, the FS system is not anchored except by its own dead weight. In these cases, as with any object resting on a roof, the horizontal forces due to wind are resisted by the frictional interface between materials. Horizontal forces are relatively small for the shallow-pitched FS arrays, and friction coefficients can be easily measured (consult with RWE Schott Solar for further information on measured friction coefficients). Table 6 shows the allowable pitch of the roof as a function of the verified friction coefficient between the baseplate and roof deck material.

Table 7: Maximum Roof Pitch for 1- and 2-Row Arrays

Verified Coefficient of Friction	Maximum Roof Pitch
0.40 (minimum)	Flat to 2-degrees
0.45	Up to 4-degrees
0.50	Up to 6-degrees
> 0.50	Up to 6-degrees

Data collected by Miles Russell

Due to the distribution of horizontal wind forces and the interconnected nature of the FS array, the issue of adequate friction is virtually assured for arrays of more than two rows. The table above applies specifically to small one-and two-row arrays and array segments.

For all arrays, the recommended roof-pitch limit is 6°. Consult RWE Schott Solar for roofs outside this limit.

# 3.7.3.3 Loading Information – Applies to All PV Arrays

**Table 8: Baseplate Specifications** 

	PV Module Type		
Parameter	ASE-300	SAPC-165 x 3	Shell 140 x 3
Base Plate dimensions	11.5" x 28.0"	11.5" x 38.0"	11.5" x 38.0 "
Base Plate area	2.24 sq. ft.	3.0 sq. ft.	3.0 sq. ft.
Loading (average for middle row position includes module(s) and baseplate with jacks)	55.8 psf	52 psf	52.4 psf

Data collected by Miles Russell

# 3.7.3.4 Applies to All Arrays - Part II

• Arrays must be located a distance equal to 10 percent of the building height, or further, from all roof edges. For example, on a 40-foot building, a minimum 4-foot space should exist between any part of the PV array and a roof edge.

- Custom analyses can be conducted to assess the wind forces for specific buildings and arrays, if required.
- Conduct tests to determine that the coefficient of friction is adequate for specific roof types. Contact RWE SS for procedure and details. This applies to arrays where attachment to the roof in some fashion is not a requirement to meet seismic issues.

# **CHAPTER 4: Conclusions and Recommendations**

The challenge in this project was clear: a new way of attaching PV modules to flat-roofed commercial buildings was needed because the cost of penetrating roofs and anchoring PV arrays to the building structure is simply too costly and undesirable for building owners. The free-standing PV system developed with support from the California Energy Commission and the National Renewable Energy Laboratory solves this problem and has become the flagship PV system offered by RWE Schott Solar Inc. Market acceptance of the FS system has been excellent and the market demand for penetrationless PV array mounting solutions seems to be growing rapidly.

# 4.1 Conclusions

The major accomplishments during this project include:

- Developed a PV array mounting system for flat roofs, the FS System, which requires no additional ballast and no roof penetrations.
- Designed the adaptability to several of RSSI's modules, including ASE-300 PV modules and assemblies of smaller modules, and others such as the SAPC-165 and Shell SP-150.
- Incorporated in the design an open architecture to promote air circulation for PV module cooling and moisture removal from the roof surface.
- Designed with durable materials for long life, and a lightweight mechanically linked array structure to insure reliable long-term performance.
- Achieved certification of the FS system for zones with winds up 130 mph.
- Achieved certification of the FS system for a penetrationless method to meet code requirements for anchoring the PV array to a building roof in any seismic zone in the United States.
- Achieved costs for the FS array mounting hardware in the demonstration array amounting to 5 percent of the total installed cost of the system.
- Identified a path to achieve further cost reduction of 20 percent to 35 percent in the fabrication of the FS hardware, through vendor selection and volume purchasing strategies.
- Developed an FS PV system installation manual for both the ASE-300 PV modules and the three-module assemblies of SAPC-165 PV modules.
- Developed an electronic permit package that will facilitate preparation of permit application packages.

# 4.2 Commercialization Potential

The free-standing PV system developed with support from the California Energy Commission and the National Renewable Energy Laboratory has become the flagship PV system offered by RWE Schott Solar Inc. Market acceptance of this PV system has been excellent and the market demand for penetrationless PV array mounting solutions seems to be growing rapidly. Cost remains the dominant driver for increasing the sales of the FS system. At present the market price for a turnkey FS system is in the range of \$7 to \$8/Wac. Payback on such a system can be as short as 6 to 10 years, depending upon the retail electric rates. In the coming year the company expects to install more than 10 MW of PV using the FS system.

# 4.3 Recommendations

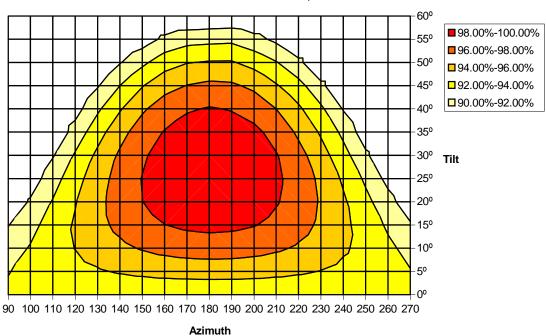
There are several opportunities that have been identified to advance the design of the new FS mounting system.

# 4.3.1 Higher Tilt Angle Version

The current mounting system design supports the PV modules at a 5° tilt angle. This allows PV arrays to be packed fairly densely in a given roof space, which is important to many customers in the California market. Although annual energy production would be maximized at a much steeper angle of 25 to 30°, the 5° tilt angle designed into the FS system is optimum when considering typical constraints on roof space. The chart below illustrates the impact of various azimuth and tilt angles for a fixed PV array on annual energy production. This is validated when one considers that the sensitivity of annual energy production to changes in tilt angle is not dramatic. The colored bands in Figure 46 show 2 percent contours of annual energy production, with the red area being 98 percent to 100 percent.

Figure 45: Effect of Tilt and Azimuth Angle on Annual Energy Production in Sacramento





The 5° tilt angle falls within the 92 percent to 94 percent band, which means that the optimum tilt angle would generate 6 to 8 percent more energy than the 5° tilt. Note that one only has to achieve a 13 or 14° tilt angle on the PV array to achieve 98 percent to 100 percent of the maximum annual energy, assuming a true-south azimuth orientation. A PV array would generate 4 percent to 6 percent more annual energy if the tilt angle were increased to 14°.

Will the same concept that makes the current mounting system effective at resisting wind forces work for a higher tilt angle as well? It is of interest to develop a higher-tilt angle system, both for increasing energy production from the modules and also in light of the proposed changes being considered for the California Energy Commission's buy down program in California. The Energy Commission is considering a pilot program based on an energy-based rebate. If this becomes the new standard, then the important metric for rebate-conscious customers will not be PV kW/square foot of roof, but PV kWh/square foot. Performance or energy-based rebates are also more rational than rebates based on nameplate rating as they reward good design and implementation.

#### 4.3.2 ICC Review

The International Codes Congress (ICC) is the organization that certifies building inspectors. This organization also offers an evaluation service whereby they will inspect and evaluate a commercial building product for its compliance with the building code. Materials that comply can then bear a mark that indicates their certification and, much like a UL listing and UL mark, this is a significant step forward for commercialization of products.

# 4.3.3 Template

A layout template was built to facilitate placement of the base plates for a recent PV array installation with this new mounting hardware. This template was not terribly useful, however, and abandoned in favor of repeated measurement using tape measures. The repeated measurement approach was quick, but development of a better template that would be quicker to use is recommended.

# 4.4 Benefits to California

California has adopted a Renewable Portfolio Standard designed to help achieve a statewide energy-production mix with 20 percent coming from non-large-hydro renewable energy sources by the year 2017. Rooftop PV systems can make a significant contribution toward this goal and RWE Schott Solar is helping make this possible with the introduction of the FS system. Since its market introduction in the summer of 2003, RWE Schott Solar's FS systems have been installed across the nation and account for a total of 6 MW of PV.

The benefits to California of widespread deployment and use of PV installations will include the obvious intrinsic advantages of photovoltaic energy that derive from less reliance on fossil fuels, and reduction of air emissions from fossil-fuel power plants. Producing energy with photovoltaic systems prevents tons of carbon dioxide, nitrous oxides, sulfur dioxide and particulates from fouling the air. Those traditional power plant emissions are contributors to both the development of smog and acid rain, and untold deleterious health effects. Greater reliance on California's indigenous solar resources also increases our nation's energy security by diversifying our energy mix and lessening our dependence on fossil fuels.

# **GLOSSARY**

Term	Definition
AC	Alternating current. An electric current that reverses direction (sine wave).in the united states, most household current is single-phase ac at 60 cycles per second. Many businesses in the U.S. that have larger electrical needs use 3-phase ac at 60 cycles per second.
AMPS OR AMPERAGE	The unit of electrical current. Can be thought of as the flow rate of electricity.
ANSI	American national standards institute.
ARRAY (PHOTOVOLTAIC)	A group of modules wired together (in a series and/or in parallel) to form an array of solar modules.
BIPV	Building-integrated photovoltaics.
CELL (PHOTOVOLTAIC)	The smallest unit of a solar module. A typical a-si solar cell is rated at 1.5 volts. A typical crystalline solar cell is rated at 0.5 volts.
CFD	Computational fluid dynamics.
COMPONENTS	Refers to other devices used and needed when building a solar system.
DC	Direct current. An electric current flowing in one direction only.
FS	Free standing.
GRID-CONNECTED (PHOTOVOLTAIC)	A photovoltaic system in which the pv array supplies power directly to a load center (for example, Ac service panel) in a home or commercial facility. There is no on-site storage device included with a grid-connected photovoltaic system. Instead, all the kilowatthours generated by the pv system are either used by the loads connected to the load center in the building or they are pulled into the utility grid power lines via the utility kilowatthour meter attached to the building.

Term	Definition
ICBO	International Congress of Building Officials (currently ICC)
ICC	International Code Council (formerly ICBO)
IEC	International electrotechnical commission
INVERTER	An electronic device that changes direct current (dc) to alternating current (ac).
KW	Kilowatt, 1000 watts; an incandescent light bulb uses 40-100 watts.
MW	Megawatt, 1,000,000 watts
MODULE (PHOTOVOLTAIC)	Pv modules are manufactured and assembled using solar cells, interconnect wire, bypass diodes, encapsulant (which is a top cover over the solar cells) and a protective back sheet behind the solar cells. Most solar modules also include a frame around the edges of the back sheet/top cover assembly. Together, all of these components form the solar pv module.
NEC	National electric code.
PHOTOVOLTAIC (PV)	Direct conversion of light into electrical energy.
Pa	Pascal, a unit of pressure equal to 1 Newton per square meter
PV	Photovoltaic.
PVSCP	Pv source circuit protector.
PHOTOVOLTAIC CELL	The treated semiconductor material that converts solar irradiance to electricity.
RSSI	Rwe Schott Solar, Inc.
SERIES CONNECTION	Connection in which the current (amps) stays the same but the voltage multiplies.
SOLAR	Energy from the sun.
SOLAR COLLECTORS	A device designed to capture light or heat energy from the sun. Solar thermal collectors

Term	Definition
	are used in solar hot water systems (often found in homes) and photovoltaic collectors are used in solar electric systems.
SOLAR PANEL	Another name for a single module or a group of solar modules that are part of a solar electric pv system.
SYSTEMS; BALANCE OF SYSTEMS	Solar electric systems include the photovoltaic array and the other components that allow these solar panels to be used in homes and commercial facilities where a regulated dc power supply or an ac power supply is required. Components used in solar electric systems include; wire and disconnect devices, charge regulators, inverters, metering, and grounding components.
UL	Underwriters laboratories Inc.
VOLTS (V)	The unit of electromotive force that will force a current of one amp through a resistor or one ohm.
VOLTAGE	The measurement of the force of electricity.
WAC	Watts alternating current
WDC	Watts direct current
WATTS	A measure of electrical power that is determined by multiplying the voltage by the amperage.

# **APPENDIX A: FS Mounting System Certification**

Attached are the certifications for the FS mounting system, for wind loading and seismic requirements.

Figure A-1: Stamped Wind Letter for California



Chicago Columbus Dallas Las Angeles Miami

June 11, 2003

Kevin Davies RWE Schott Solar 4051 Alvis Court, Suite 1 Rocklin, CA 95677

Re: Wind Analysis of SunRoof FS System

Mr. Davies.

This letter serves as verification that the roof installed solar panel system, SunRoof FS, will resist all uplift and sliding forces created by wind speeds up to 130 mph when installed on a flat roof without the addition of ballast or mechanical attachment to the roof structure. The wind speed of 130 mph corresponds to that definition as provided in ASCE 7-98, Minimum Design Loads for Buildings and Other Structure, published by the American Society of Civil Engineers.

This conclusion is based upon the report provided by RWE Schott Solar entitled, Wind Testing and Analysis of the RWE SS FS PV Array Mounting System. This report contains analyses results from wind tunnel tests performed at the Massachusetts Institute of Technology (MIT) for a single unit and also computer generated computational fluid dynamics modeling (CFD) performed by Newmerical Technologies International for large solar panel arrays at various wind directions. Uplift pressures resulting from the CFD modeling were calculated using FENSAP-AIRWAKE proprietary software as developed by Newmerical Technologies.

This analysis is supported by ASCE 7-98, section 6.6, under Method 3 — Wind Tunnel Procedure, which states in section 6.6.1: Wind tunnel testing shall be permitted in lieu of Methods 1 and 2 for any building or structure. Note that methods 1 and 2 are prescriptive methods based on the equations and tabulated variables provided in this code. Also, since the 130 mph limit in maximum tolerable wind speed for this product is directly related to the definition of wind speed provided in ASCE 7-98, the wind speed map as provided on pages 34 and 35 of ASCE 7-98 provides a good indication of those areas of the United States where the wind speed exceeds 130 mph and thus where the SunRoof FS system will require modification to achieve code compliant installation.

If you have any further questions concerning the analysis or conclusions, please contact me at (614) 324-5503.

Sincerely

Christopher P. Sekol, P.E. Structural Engineer

Brett Gilbert, F.E.
Director of Civil Engineering

CIVIL G

1201 Dublin Road Columbus, 0H 43215-1026 T 614.221.0840 F 614.221.2484



Chicago Columbus Dailas Los Angeles Miami

June 11, 2003

Kevin Davies RWE Schott Solar 4051 Alvis Court, Suite 1 Rocklin, CA 95677

Re: Seismic Analysis of SunRoof FS System

Mr. Davies,

This letter serves as verification that the roof installed solar panel system, SunRoof FS, will resist all overturning and sliding forces created by seismic activity in Zones 3 and 4 as defined in the 1997 Uniform Building Code (UBC).

Based on the testing information provided by RWE Schott Solar concerning the actual coefficient of friction at the interface of the base plates of the SunRoof system and the roof surface, the lowest value provided was 0.64. In seismic Zone 4, 60% of the weight of the solar panel system (0.6 x W) will be the effective horizontal force causing sliding and overturning potential. Since the coefficient of friction is typically greater than the percentage of weight required to be considered for lateral forces, sliding will realistically be resisted by friction. However, section 1632.1 of the UBC states, "Friction resulting from gravity loads shall not be considered to provide resistance to seismic forces." Therefore for the purpose of design, the system shall be attached to the roof with adhesive. Regardless, It is important to note frictional resistance to identify the fact that it does practically increase the effective safety factor against sliding.

Considering the use of adhesive to resist shear forces, a typical allowable strength value is 8 psi. Therefore, the shear capacity of one 11.5 inch x 28 inch base plate, adhered to the roof is 2,576 pounds. Since the average weight of the SunRoof system, including solar panels and base plates, is approximately 4.0 pounds per square foot, the corresponding seismic lateral force is 0.6 x 4.0 = 2.4 psf. For an array that averages 15,000 square feet of area in plan, the total seismic lateral force is 15,000 x 2.4 = 36,000 pounds. An array of 15,000 square feet would require approximately 480 base plates. If only one-half of all the base plates that form the perimeter, effective in resisting forces in only one direction (20 base plates) of the 15,000 square feet array, were adhered to the roof membrane, the total resistive force is 20 x 2,576 = 51,520 pounds. This results in a safety factor of 1.43 (51,520/36,000 = 1.43).

Overturning of the base plates or solar panels is not an issue either. The SunRoof system is designed such that each solar panel is supported on the (4) corners with a base plate. Each base plate, in turn, supports (1) corner of (4) other solar panels, except for perimeter pieces, of course. This interlocking arrangement nearly eliminates the

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Figure A-2: Stamped Seismic Letter for California



mechanism for overturning. This concept is best understood by reviewing the supplemental calculations.

In conclusion, for every 15,000 square feet array of panels, 50% of the perimeter base plates should be adhered to the roof membrane to achieve a safe installation to resist seismic forces.

If you have any further questions concerning the analysis or conclusions, please contact me at (614) 324-5503.

Sincerely,

Christopher P. Sekol, P.E. Structural Engineer

Director of Civil Engineering

BRETT GILBERT